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Oskotsky et al.

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(54) **COMPACT AND ATHERMAL VNIR/SWIR SPECTROMETER**

(71) Applicant: **BAE Systems Information and Electronic Systems Integration Inc.**, Nashua, NH (US)

(72) Inventors: **Mark L Oskotsky**, Mamaroneck, NY (US); **Michael J Russo, Jr.**, Roslyn, NY (US)

(73) Assignee: **BAE Systems Information and Electronics Systems Integration Inc.**, Nashua, NH (US)

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(22) Filed: **Jul. 11, 2017**

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(51) **Int. Cl.**
G01J 3/02 (2006.01)
G01J 3/04 (2006.01)

(52) **U.S. Cl.**
CPC **G01J 3/0208** (2013.01); **G01J 3/0256** (2013.01); **G01J 3/04** (2013.01)

(58) **Field of Classification Search**
CPC G01J 3/0208; G01J 3/0256; G01J 3/04
USPC 250/339.01, 339.02, 339.07
See application file for complete search history.

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(Continued)

Primary Examiner — David P Porta

Assistant Examiner — Blake C Riddick

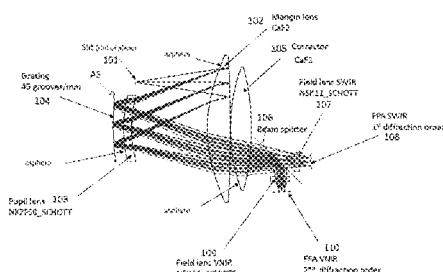
(74) *Attorney, Agent, or Firm* — Maine Cernota & Rardin

(57) **ABSTRACT**

A Compact and Athermal VNIR/SWIR Spectrometer utilizes a slit, a Mangin lens, a pupil lens adjacent to the diffraction grating, corrector lenses, a beam splitter, field lenses and SWIR and VNIR FPAs. In examples, two corrector lenses are used. Some examples do not utilize field lenses and beam splitter, some examples utilize only the SWIR radiation spectrum. By balancing the powers of the optical elements and Abbe numbers of glasses as well as usage of aspheric surfaces combinations, a monochromatic and polychromatic aberrational correction is achieved; by balancing optical elements refractive indices change with temperature an athermalization is achieved. The overall length of the spectrometer does not exceed 4 inches, and in some examples it is 2.5 inches. A wide field of view and a low F number are obtained with an operating wavelength range from approximately 400 to 2350 nm. The spectrometer is particularly suited to airborne applications.

20 Claims, 19 Drawing Sheets

100



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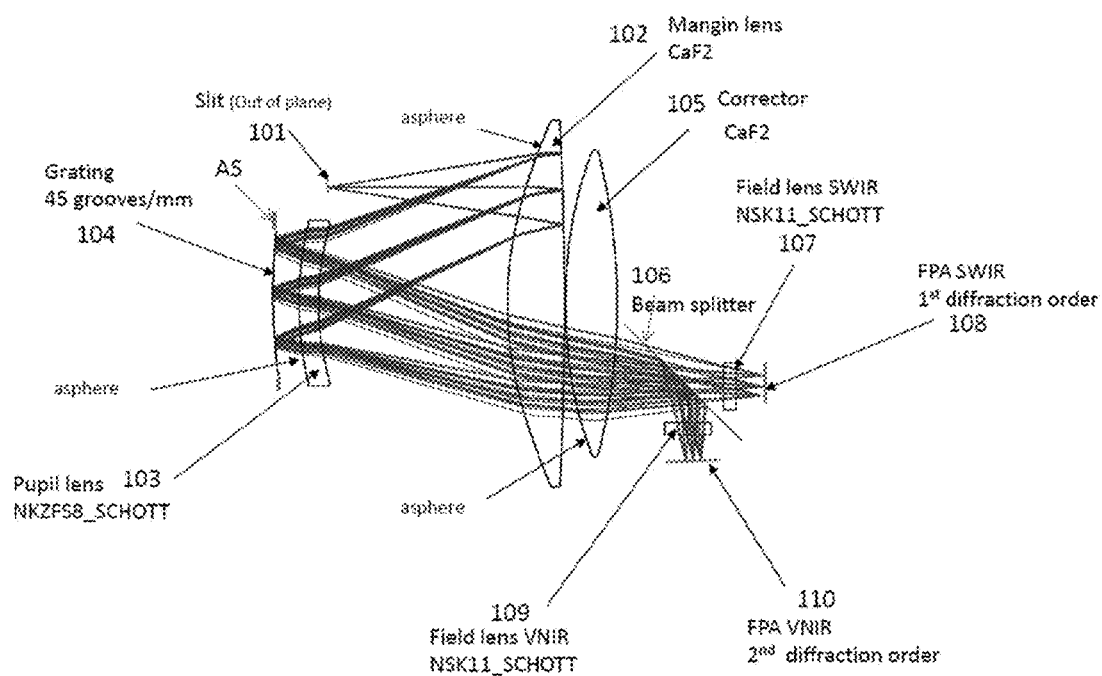
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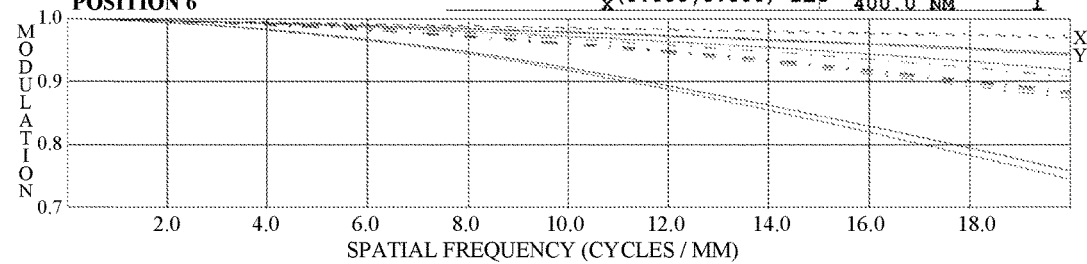
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FIRST EMBODIMENT
FIG. 1

200

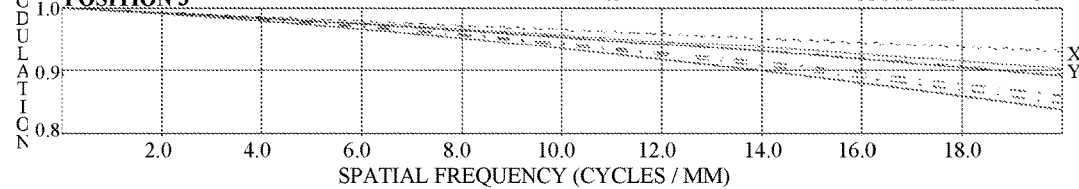
WL 400NM

DIFFRACTION MTF
DEFOCUSING 0.00000
POSITION 6



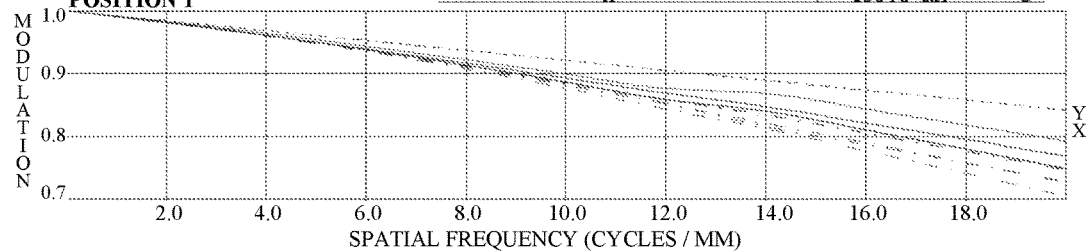
WL 1000NM

DIFFRACTION MTF
DEFOCUSING 0.00000
POSITION 3



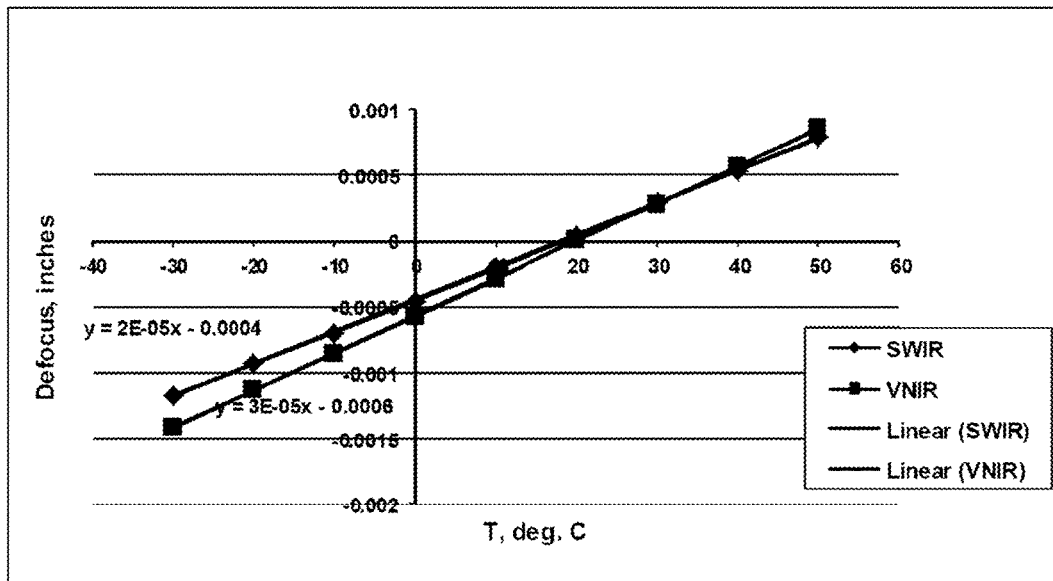
WL 2350NM

DIFFRACTION MTF
DEFOCUSING 0.00000
POSITION 1



MTF FOR FIRST EMBODIMENT

FIG. 2



SWIR: 43 MICRONS DEFOCUS RANGE FOR -20DEG. C TO + 40 DEG. C

THERMAL DEFOCUS FOR FIRST EMBODIMENT
FIG. 3

```
RDY      THI  RMD  GLA      CCY  THC  GLC
> OBJ:    INFINITY  1.401168      100  0
1:  2.71015  0.450000  CAF2_SCHOTT  10 100
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-1.64000E-01 B :0.295828E-02 C :-1.02841E-02 D :0.122243E-03
AC : 77  BC : 78  CC : 79  DC : 80
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000
XDC: 100  YDC: 100  ZDC: 100
ADE: -0.247952 BDE: 0.000000 CDE: 0.000000
ADC: 0  BDC: 100  CDC: 100

2:  -25.75095  -0.450000 REFL CAF2_SCHOTT  -1 PIK
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000 BEN
XDC: 100  YDC: 100  ZDC: 100
ADE: 0.000000 BDE: 0.000000 CDE: 0.000000
ADC: 100  BDC: 100  CDC: 100

3:  2.71015  -1.468711      PIK 22
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-1.64000E-01 B :0.295828E-02 C :-1.02841E-02 D :0.122243E-03
AC : 77  BC : 78  CC : 79  DC : 80

4:  2.12104  -0.150000  NKZFS8_SCHOTT  20 100
5:  2.60885  -0.200000      30 32
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-6.66628E-02 B :0.689624E-03 C :-1.47752E-01 D :0.233786E-01
AC : 23  BC : 24  CC : 26  DC : 27

STO:  4.88170  0.200000 REFL      0 PIK
GRT:
GRO: 1.000000 GRS: 0.000880
ROC: 100  RSC: 0
GRX: 0.000000 GRY: 1.000000 GRZ: 0.000000
RXC: 100  RYC: 100  RZC: 100
      BLT: IDEAL
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000 DAR
XDC: 100  YDC: 100  ZDC: 100
ADE: 0.865734 BDE: 0.000000 CDE: 0.000000
ADC: 0  BDC: 100  CDC: 100

7:  2.60885  0.150000  NKZFS8_SCHOTT  PIK PIK PIK
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-6.66628E-02 B :0.689624E-03 C :-1.47752E-01 D :0.233786E-01
AC : 23  BC : 24  CC : 26  DC : 27

8:  2.12104  1.468711      PIK -22
9:  2.71015  0.450000  CAF2_SCHOTT  PIK PIK PIK
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-1.64000E-01 B :0.295828E-02 C :-1.02841E-02 D :0.122243E-03
AC : 77  BC : 78  CC : 79  DC : 80
```

10: -25.75095 0.005000 PIK 0
11: 3.82977 0.400000 CAF2_SCHOTT 0 100
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :0.966888E-02 B :0.442417E-02 C :-.303709E-02 D :0.676723E-03
AC : 0 BC : 0 CC : 0 DC : 0

12: -4.70553 0.305174 0 0
13: INFINITY 0.521115 AIR 100 55
XDE: 0.000000 YDE: -0.400000 ZDE: 0.000000 BEN
XDC: 100 YDC: 100 ZDC: 100
ADE: 0.000000 BDE: 0.000000 CDE: 0.000000
ADC: 100 BDC: 100 CDC: 100

14: 11.04175 0.100000 NSK11_SCHOTT 14 100
XDE: 0.000000 YDE: -0.345433 ZDE: 0.000000
XDC: 100 YDC: 0 ZDC: 100
ADE: 0.000000 BDE: 0.000000 CDE: 0.000000
ADC: 100 BDC: 100 CDC: 100

15: -25.65589 0.200000 16 110
IMG: INFINITY 0.000000 100 100
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000 DAR
XDC: 100 YDC: 100 ZDC: 100
ADE: -3.446832 BDE: -0.000796 CDE: 0.000000
ADC: 76 BDC: 93 CDC: 100

SPECIFICATION DATA

FNO	3.30000					
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DIM	IN					
WL	2350.00	1625.00	1000.00	900.00	650.00	400.00
REF	1					
WTW	1	0	0	0	0	0
XOB	0.00000	0.34000	0.68000	-0.34000	-0.68000	
YOB	0.90000	0.90000	0.90000	0.90000	0.90000	
WTF	1.00000	1.00000	1.00000	1.00000	1.00000	
VUX	0.00000	0.00000	0.00000	0.00000	0.00000	
VLX	0.00000	0.00000	0.00000	0.00000	0.00000	
VUY	0.00000	0.00000	0.00000	0.00000	0.00000	
VLY	0.00000	0.00000	0.00000	0.00000	0.00000	
POL	N					

APERTURE DATA/EDGE DEFINITIONS

CA APE

APERTURE data not specified for surface Obj thru 16

REFRACTIVE INDICES

GLASS CODE	2350.00	1625.00	1000.00	900.00	650.00	400.00
CAF2_SCHOTT	1.421984	1.425685	1.428893	1.429622	1.432570	1.441834
NKZFS8_SCHOTT	1.674739	1.687806	1.699630	1.702511	1.714842	1.759626
NSK11_SCHOTT	1.535575	1.545780	1.553508	1.555097	1.561235	1.580173

No solves defined in system

PICKUPS

PIK THI S6 Z1 THI S5 Z1 -1.000000
 PIK RDY S10 Z1 RDY S2 Z1
 PIK RDY S3 Z1 RDY S1 Z1
 PIK RDY S9 Z1 RDY S1 Z1
 PIK RDY S8 Z1 RDY S4 Z1
 PIK RDY S7 Z1 RDY S5 Z1
 PIK GLA S7 Z1 GLA S4 Z1
 PIK THI S7 Z1 THI S4 Z1 -1.000000
 PIK THI S2 Z1 THI S1 Z1 -1.000000
 PIK THI S9 Z1 THI S1 Z1
 PIK GLA S9 Z1 GLA S1 Z1

ZOOM DATA

	POS 1	POS 2	POS 3	POS 4	POS 5	POS 6
WTW W1	1	0	0	0	0	0
WTW W2	0	1	0	0	0	0
WTW W3	0	0	1	0	0	0
WTW W4	0	0	0	1	0	0
WTW W5	0	0	0	0	1	0
WTW W6	0	0	0	0	0	1
REF	1	2	3	4	5	6
GRO S6	1.00000	1.00000	1.00000	2.00000	2.00000	2.00000
ROC S6	100	100	100	100	100	100
RMD S13	REFR	REFR	REFR	REFL	REFL	REFL
THI S13	0.52111	0.52111	0.52111	-0.52207	-0.52207	-0.52207
THC S13	55	55	55	56	56	56
ADE S13	0.00000	0.00000	0.00000	45.00000	45.00000	45.00000
ADC S13	100	100	100	100	100	100
THI S14	0.10000	0.10000	0.10000	-0.10000	-0.10000	-0.10000
THC S14	100	100	100	100	100	100
RDY S14	11.04175	11.38338	11.38338	-25.23347	-25.23347	-25.23347
CCY S14	14	14	14	15	15	15
THI S15	0.20000	0.20000	0.20000	-0.20000	-0.20000	-0.20000
THC S15	110	110	110	111	111	111
RDY S15	-25.65589	-27.44947	-27.44947	21.29391	21.29391	21.29391
CCY S15	16	16	16	17	17	17
THI S16	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
THC S16	100	100	100	100	100	100
ADE S16	-3.44683	-3.44683	-3.44683	2.49728	2.49728	2.49728
ADC S16	76	76	76	77	77	77
BDE S16	-0.00080	-0.00080	-0.00080	-0.00492	-0.00492	-0.00492
BDC S16	93	93	93	94	94	94
RDY S16	INFINITY	INFINITY	INFINITY	INFINITY	INFINITY	INFINITY
CCY S16	100	100	100	100	100	100
GL1 S13	AIR	AIR	AIR	AIR	AIR	AIR
GC1 S13	100	100	100	100	100	100
GP1 S13	AIR	AIR	AIR	AIR	AIR	AIR

This is a non-symmetric system. If elements with power are decentered or tilted, the first order properties are probably inadequate in describing the system characteristics.

	POS 1	POS 2	POS 3	POS 4	POS 5	POS 6
INFINITE CONJUGATES						
EFL	7.8461	7.9778	8.2461	-7.1147	-7.2902	-7.9017
BFL	-7.6635	-7.8021	-8.0727	6.9798	7.1581	7.7777
FFL	6.4450	6.5726	6.8410	5.6713	5.8451	6.4486
FNO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AT USED CONJUGATES						
RED	1.0000	1.0005	1.0005	1.0060	1.0061	1.0066
FNO	3.3000	3.3000	3.3000	3.3000	3.3000	3.3000
OBJ DIS	1.4012	1.4012	1.4012	1.4012	1.4012	1.4012
TT	3.3825	3.3825	3.3825	1.7393	1.7393	1.7393
IMG DIS	0.2000	0.2000	0.2000	-0.2000	-0.2000	-0.2000
OAL	1.7813	1.7813	1.7813	0.5381	0.5381	0.5381
PARAXIAL IMAGE						
HT	0.9000	0.9005	0.9004	0.9054	0.9055	0.9060
THI	0.1825	0.1797	0.1774	-0.1774	-0.1762	-0.1762
ANG	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ENTRANCE PUPIL						
DIA	0.3066E+10	0.3067E+10	0.3067E+10	0.3084E+10	0.3085E+10	0.3086E+10
THI	0.1000E+11	0.1000E+11	0.1000E+11	0.1000E+11	0.1000E+11	0.1000E+11
EXIT PUPIL						
DIA	2.4054	2.4470	2.5293	2.1945	2.2488	2.4388
THI	-7.6635	-7.8021	-8.0727	6.9798	7.1581	7.7777
STO DIA	1.0278	1.0114	0.9967	0.9977	0.9843	0.9427

500

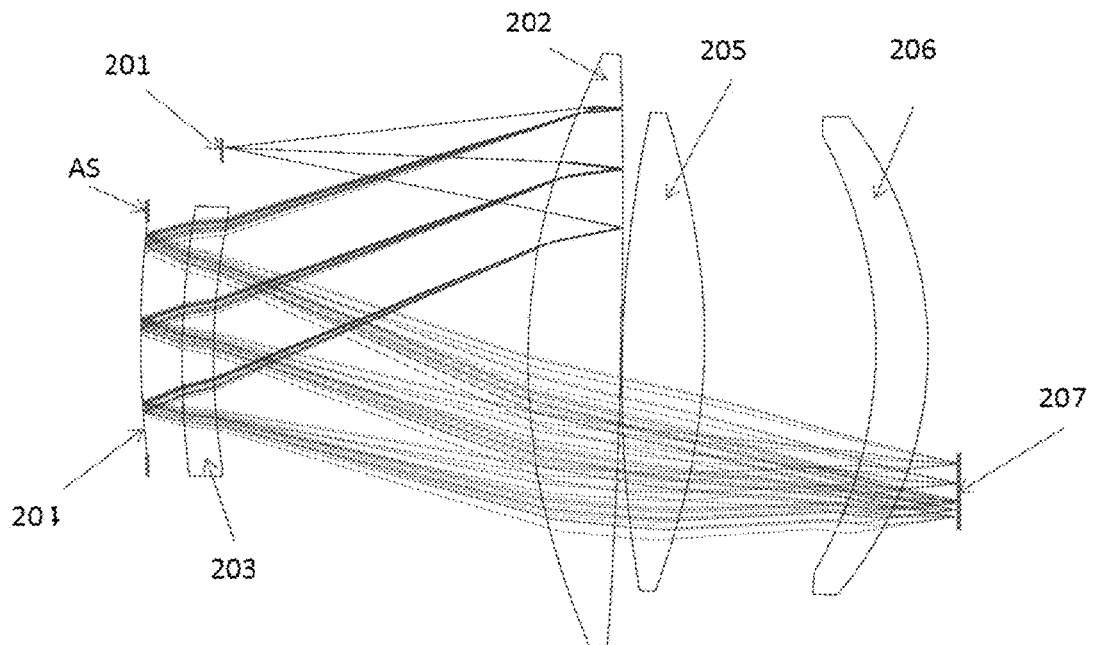
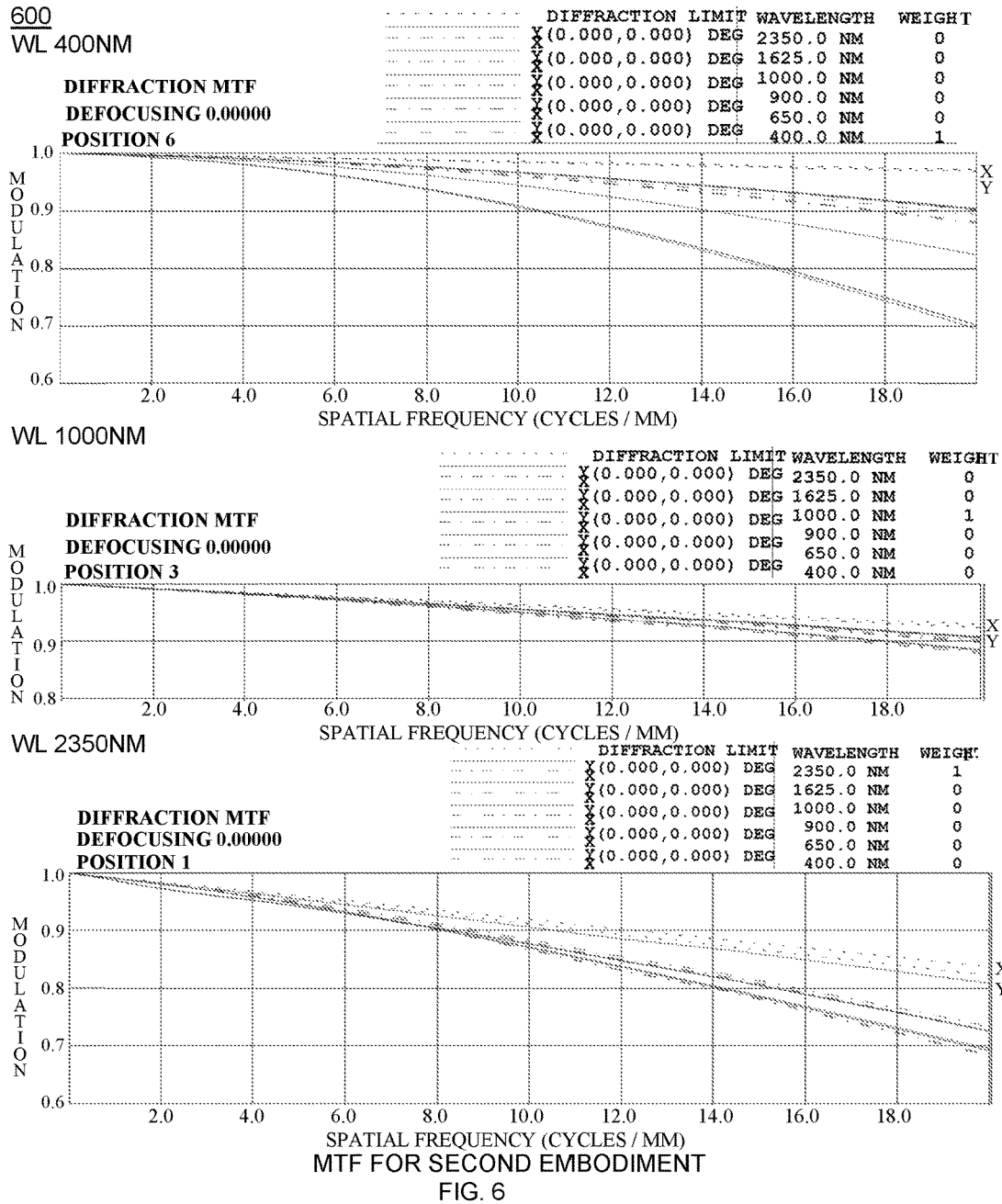


FIG. 5



RDY THI RMD GLA CCY THC GLC
> OBJ: INFINITY 1.502546 100 0
1: 2.84850 0.450000 CAF2_SCHOTT 10 100
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-139793E-01 B :0.252997E-02 C :-940048E-03 D :0.126025E-03
AC : 77 BC : 78 CC : 79 DC : 80
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000
XDC: 100 YDC: 100 ZDC: 100
ADE: 1.101800 BDE: 0.000000 CDE: 0.000000
ADC: 0 BDC: 100 CDC: 100

2: -31.22769 -0.450000 REFL CAF2_SCHOTT -1 PIK
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000 BEN
XDC: 100 YDC: 100 ZDC: 100
ADE: 0.000000 BDE: 0.000000 CDE: 0.000000
ADC: 100 BDC: 100 CDC: 100

3: 2.84850 -1.519515 PIK 22
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-139793E-01 B :0.252997E-02 C :-940048E-03 D :0.126025E-03
AC : 77 BC : 78 CC : 79 DC : 80

4: 3.31227 -0.150000 NKZFS8_SCHOTT 20 100
5: 4.29497 -0.200000 30 32
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-651529E-02 B :0.126478E-02 C :-119493E-01 D :0.132354E-01
AC : 23 BC : 24 CC : 26 DC : 27

STO: 5.01583 0.200000 REFL 0 PIK
GRT:
GRO: 1.000000 GRS: 0.000810
ROC: 100 RSC: 0
GRX: 0.000000 GRY: 1.000000 GRZ: 0.000000
RXC: 100 RYC: 100 RZC: 100
BLT: IDEAL
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000 DAR
XDC: 100 YDC: 100 ZDC: 100
ADE: 1.303786 BDE: 0.000000 CDE: 0.000000
ADC: 0 BDC: 100 CDC: 100

7: 4.29497 0.150000 NKZFS8_SCHOTT PIK PIK PIK
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-651529E-02 B :0.126478E-02 C :-119493E-01 D :0.132354E-01
AC : 23 BC : 24 CC : 26 DC : 27

8: 3.31227 1.519515 PIK -22
9: 2.84850 0.450000 CAF2_SCHOTT PIK PIK PIK
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-139793E-01 B :0.252997E-02 C :-940048E-03 D :0.126025E-03
AC : 77 BC : 78 CC : 79 DC : 80

10: -31.22769 0.005000 PIK 0
11: 6.00514 0.400000 CAF2_SCHOTT 0 100
12: -2.84553 0.825485 0 0
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :0.113907E-01 B :0.117317E-03 C :0.233777E-02 D :-.146342E-03
AC : 0 BC : 0 CC : 0 DC : 0

13: -2.12368 0.250000 NSK11_SCHOTT 0 100
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000
XDC: 100 YDC: 100 ZDC: 100
ADE: 0.000000 BDE: 0.000000 CDE: 0.000000
ADC: 100 BDC: 100 CDC: 100

14: -1.81180 0.200000 0 110
IMG: INFINITY 0.000000 100 100
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000 DAR
XDC: 100 YDC: 100 ZDC: 100
ADE: -3.840739 BDE: 0.002375 CDE: 0.000000
ADC: 76 BDC: 93 CDC: 100

SPECIFICATION DATA

FNO 3.30000
TEL
DIM IN
WL 2350.00 1625.00 1000.00 900.00 650.00 400.00
REF 1
WTW 1 0 0 0 0 0
XOB 0.00000 0.34000 0.68000 -0.34000 -0.68000
YOB 0.90000 0.90000 0.90000 0.90000 0.90000
WTF 1.00000 1.00000 1.00000 1.00000 1.00000
VUX 0.00000 0.00000 0.00000 0.00000 0.00000
VLX 0.00000 0.00000 0.00000 0.00000 0.00000
VUY 0.00000 0.00000 0.00000 0.00000 0.00000
VLY 0.00000 0.00000 0.00000 0.00000 0.00000
POL N

APERTURE DATA/EDGE DEFINITIONS

CA APE

APERTURE data not specified for surface Obj thru 15

REFRACTIVE INDICES

GLASS CODE	2350.00	1625.00	1000.00	900.00	650.00	400.00
CAF2_SCHOTT	1.421984	1.425685	1.428893	1.429622	1.432570	1.441834
NKZFS8_SCHOTT	1.674739	1.687806	1.699630	1.702511	1.714842	1.759626
NSK11_SCHOTT	1.535575	1.545780	1.553508	1.555097	1.561235	1.580173

No solves defined in system

PICKUPS

PIK THI S6 Z1 THI S5 Z1 -1.000000
 PIK RDY S10 Z1 RDY S2 Z1
 PIK RDY S3 Z1 RDY S1 Z1
 PIK RDY S9 Z1 RDY S1 Z1
 PIK RDY S8 Z1 RDY S4 Z1
 PIK RDY S7 Z1 RDY S5 Z1
 PIK GLA S7 Z1 GLA S4 Z1
 PIK THI S7 Z1 THI S4 Z1 -1.000000
 PIK THI S2 Z1 THI S1 Z1 -1.000000
 PIK THI S9 Z1 THI S1 Z1
 PIK GLA S9 Z1 GLA S1 Z1

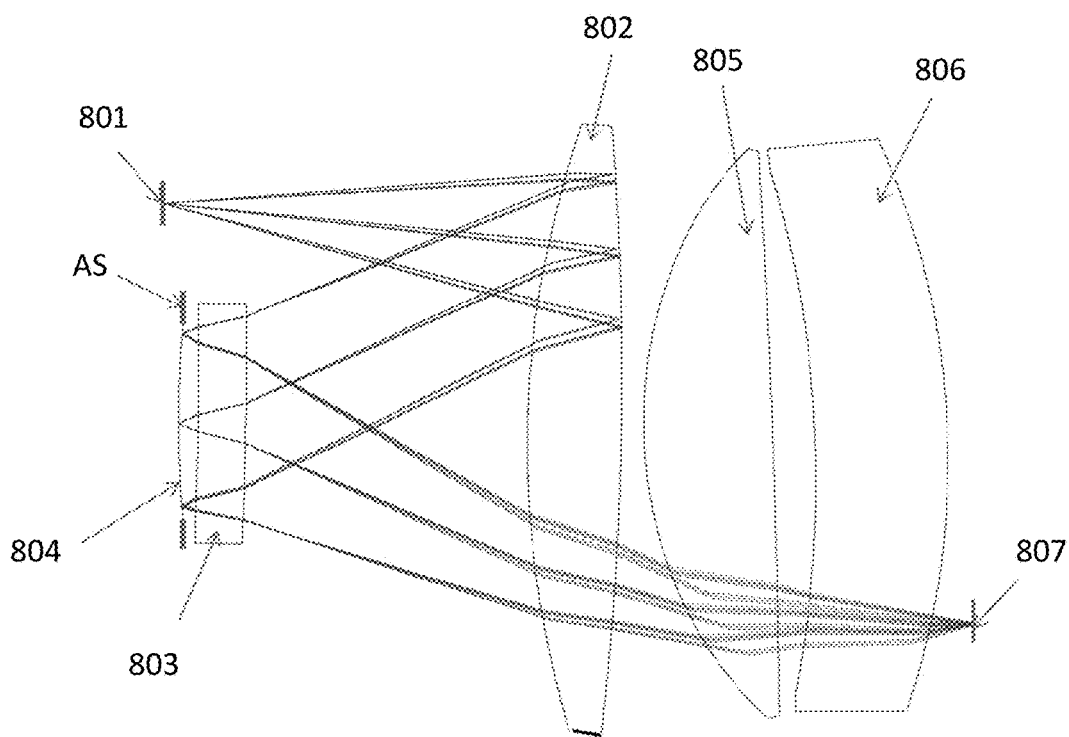
ZOOM DATA

	POS 1	POS 2	POS 3	POS 4	POS 5	POS 6
WTW W1	1	0	0	0	0	0
WTW W2	0	1	0	0	0	0
WTW W3	0	0	1	0	0	0
WTW W4	0	0	0	1	0	0
WTW W5	0	0	0	0	1	0
WTW W6	0	0	0	0	0	1
REF	1	2	3	4	5	6

This is a non-symmetric system. If elements with power are decentered or tilted, the first order properties are probably inadequate in describing the system characteristics.

	POS 1	POS 2	POS 3	POS 4	POS 5	POS 6
INFINITE CONJUGATES						
EFL	8.0374	8.3490	8.6303	8.6954	8.9661	9.9356
BFL	-7.9099	-8.2264	-8.5120	-8.5779	-8.8519	-9.8299
FFL	6.5349	6.8442	7.1234	7.1880	7.4565	8.4173
FNO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AT USED CONJUGATES						
RED	1.0000	1.0003	1.0005	1.0006	1.0008	1.0016
FNO	3.3000	3.3000	3.3000	3.3000	3.3000	3.3000
OBJ DIS	1.5025	1.5025	1.5025	1.5025	1.5025	1.5025
TT	3.6330	3.6330	3.6330	3.6330	3.6330	3.6330
IMG DIS	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
OAL	1.9305	1.9305	1.9305	1.9305	1.9305	1.9305
PARAXIAL IMAGE						
HT	0.9000	0.9002	0.9005	0.9005	0.9007	0.9014
THI	0.1275	0.1248	0.1227	0.1223	0.1212	0.1215
ANG	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ENTRANCE PUPIL						
DIA	0.3066E+10	0.3067E+10	0.3067E+10	0.3067E+10	0.3068E+10	0.3071E+10
THI	0.1000E+11	0.1000E+11	0.1000E+11	0.1000E+11	0.1000E+11	0.1000E+11
EXIT PUPIL						
DIA	2.4640	2.5602	2.6472	2.6673	2.7509	3.0509
THI	-7.9099	-8.2264	-8.5120	-8.5779	-8.8519	-9.8299
STO DIA	1.0424	1.0270	1.0136	1.0106	0.9983	0.9600

800



THIRD EMBODIMENT
FIG. 8

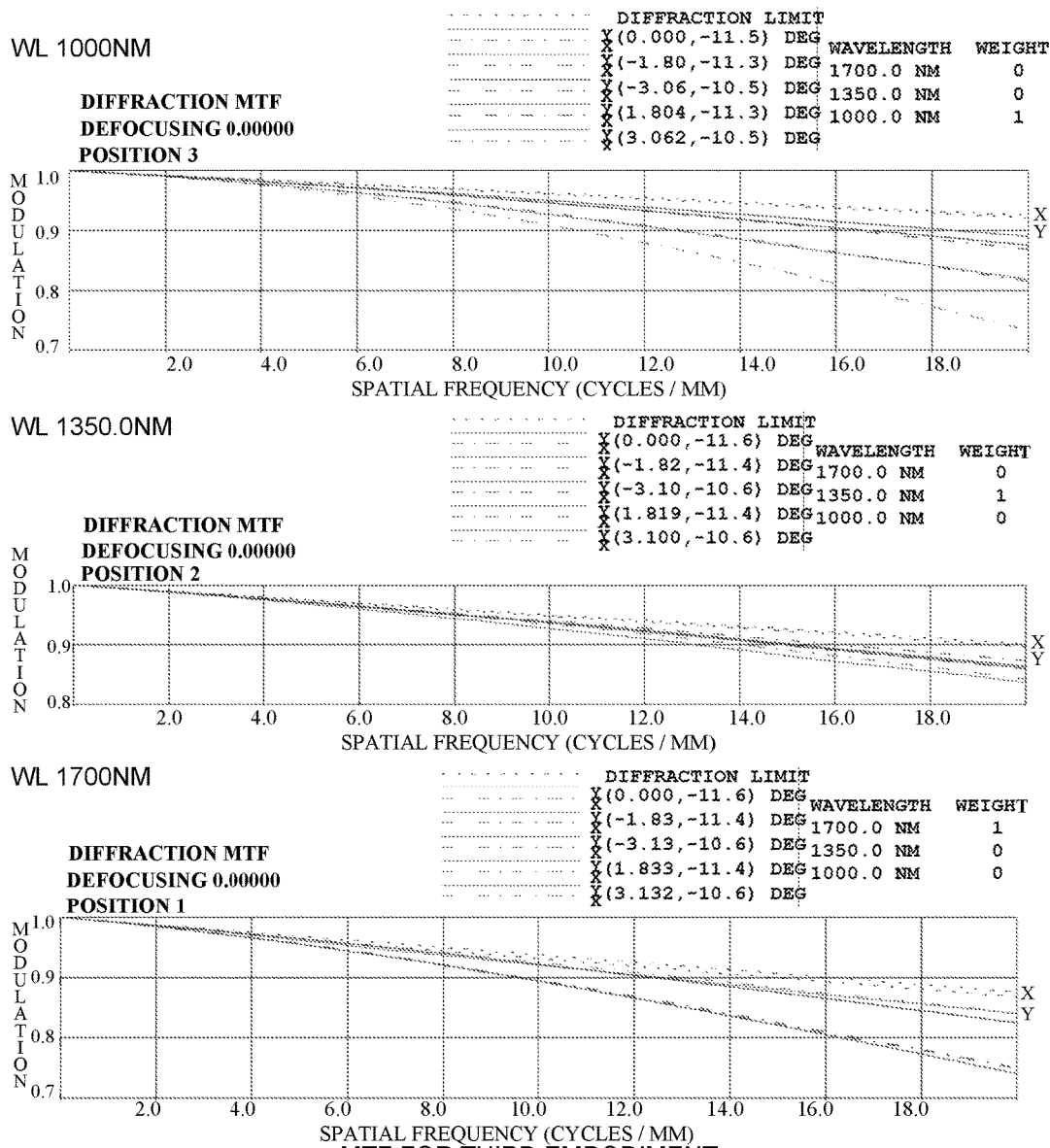


FIG. 9

```
RDY    THI    RMD    GLA    CCY    THC    GLC
> OBJ:  INFINITY  1.090096      100    0
1:      2.71608    0.300000    CAF2_SCHOTT    10    100
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-3.72926E-01 B :0.279464E-01 C :-1.86547E-01 D :0.547909E-02
AC : 77 BC : 78 CC : 79 DC : 80
XDE: 0.000000 YDE: 0.184540 ZDE: 0.000000
XDC: 100 YDC: 0 ZDC: 100
ADE: -6.191564 BDE: 0.000000 CDE: 0.000000
ADC: 0 BDC: 100 CDC: 100

2:      -9.96694    -0.300000    REFL CAF2_SCHOTT    -1    PIK
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000 BEN
XDC: 100 YDC: 100 ZDC: 100
ADE: 0.000000 BDE: 0.000000 CDE: 0.000000
ADC: 100 BDC: 100 CDC: 100

3:      2.71608    -0.897105      PIK    22
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-3.72926E-01 B :0.279464E-01 C :-1.86547E-01 D :0.547909E-02
AC : 77 BC : 78 CC : 79 DC : 80

4:      -15.15470    -0.150000    NKZFS8_SCHOTT    20    100
5:      -10.41453    -0.061868      30    32
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-6.03062E-02 B :-4.74751E+00 C :0.706474E+01 D :-3.54609E+02
AC : 23 BC : 24 CC : 26 DC : 27

STO:      3.56659    0.061868    REFL      0    PIK
GRT:
GRO: 1.000000 GRS: 0.005621
ROC: 100 RSC: 0
GRX: 0.000000 GRY: 1.000000 GRZ: 0.000000
RXC: 100 RYC: 100 RZC: 100
BLT: IDEAL
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000 DAR
XDC: 100 YDC: 100 ZDC: 100
ADE: 1.016245 BDE: 0.000000 CDE: 0.000000
ADC: 0 BDC: 100 CDC: 100

7:      -10.41453    0.150000    NKZFS8_SCHOTT    PIK    PIK    PIK
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-6.03062E-02 B :-4.74751E+00 C :0.706474E+01 D :-3.54609E+02
AC : 23 BC : 24 CC : 26 DC : 27

8:      -15.15470    0.897105      PIK    -22
9:      2.71608    0.300000    CAF2_SCHOTT    PIK    PIK    PIK
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :-3.72926E-01 B :0.279464E-01 C :-1.86547E-01 D :0.547909E-02
AC : 77 BC : 78 CC : 79 DC : 80

10:      -9.96694    0.071766      PIK    0
11:      1.36912    0.409979    SFPL53_OHARA      0    0
ASP:
K : 0.000000 KC : 100
CUF: 0.000000 CCF: 100
A :0.125953E-01 B :0.255522E-01 C :0.115246E-02 D :0.190225E-01
AC : 0 BC : 0 CC : 0 DC : 0
XDE: 0.000000 YDE: -0.020352 ZDE: 0.000000
XDC: 100 YDC: 0 ZDC: 100
ADE: 3.135848 BDE: 0.000000 CDE: 0.000000
ADC: 0 BDC: 100 CDC: 100
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12: -33.04502 0.135466 0 0
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000
XDC: 100 YDC: 100 ZDC: 100
ADE: 0.000000 BDE: 0.000000 CDE: 0.000000
ADC: 100 BDC: 100 CDC: 100

13: -3.35739 0.420000 STIH53_OHARA 0 0
XDE: 0.000000 YDE: 0.008628 ZDE: 0.000000
XDC: 100 YDC: 0 ZDC: 100
ADE: 0.731002 BDE: 0.000000 CDE: 0.000000
ADC: 0 BDC: 100 CDC: 100

14: -2.43679 0.053816 0 0
XDE: 0.000000 YDE: 0.000000 ZDE: 0.000000
XDC: 100 YDC: 100 ZDC: 100
ADE: 0.000000 BDE: 0.000000 CDE: 0.000000
ADC: 100 BDC: 100 CDC: 100

IMG: INFINITY 0.000000 100 100
XDE: -0.000000 YDE: -0.638837 ZDE: 0.000000 DAR
XDC: 0 YDC: 0 ZDC: 100
ADE: -3.076922 BDE: 0.000000 CDE: 0.000000
ADC: 0 BDC: 100 CDC: 100

SPECIFICATION DATA

FNO 3.00000
DIM IN
WL 1700.00 1350.00 1000.00
REF 1
WTW 1 0 0
XOB 0.00000 0.24000 0.48000 -0.24000 -0.48000
YOB 1.00000 1.00000 1.00000 1.00000 1.00000
WTF 1.00000 1.00000 1.00000 1.00000 1.00000
VUX -0.03234 -0.01943 -0.01104 -0.02538 0.00000
VLX -0.03234 -0.02538 0.00000 -0.01943 -0.01104
VUY 0.00000 -0.00072 0.00000 -0.00072 0.00000
VLY -0.03031 -0.02595 -0.01320 -0.02595 -0.01320
POL N

APERTURE DATA/EDGE DEFINITIONS

CA APE
CIR S0 1.109234
CIR S1 0.909943
CIR S2 0.904187
CIR S3 0.874098
CIR S4 0.342176
CIR S5 0.303994
CIR S6 0.283368
CIR S7 0.281381
CIR S8 0.303909
CIR S9 0.693199
CIR S10 0.730739
CIR S11 0.844289
CIR S12 0.835544
CIR S13 0.833988
CIR S14 0.848410
CIR S15 0.465706

REFRACTIVE INDICES

GLASS CODE	1700.00	1350.00	1000.00
CAF2_SCHOTT	1.425332	1.426979	1.428893
NKZFS8_SCHOTT	1.686559	1.692437	1.699630
SFPL53_OHARA	1.429311	1.431354	1.433565
STIH53_OHARA	1.796934	1.803780	1.813453

No solves defined in system

PICKUPS

PIK THI S6 Z1 THI S5 Z1 -1.000000
PIK RDY S10 Z1 RDY S2 Z1
PIK RDY S3 Z1 RDY S1 Z1
PIK RDY S9 Z1 RDY S1 Z1
PIK RDY S8 Z1 RDY S4 Z1
PIK RDY S7 Z1 RDY S5 Z1
PIK GLA S7 Z1 GLA S4 Z1
PIK THI S7 Z1 THI S4 Z1 -1.000000
PIK THI S2 Z1 THI S1 Z1 -1.000000
PIK THI S9 Z1 THI S1 Z1
PIK GLA S9 Z1 GLA S1 Z1

ZOOM DATA

	POS 1	POS 2	POS 3
WTW W1	1	0	0
WTW W2	0	1	0
WTW W3	0	0	1
REF	1	2	3
VUY F1	-0.1490E-08	-0.1490E-08	-0.1490E-08
VLX F1	-0.03031	-0.03093	-0.03182
VUY F2	-0.00072	-0.00216	-0.00225
VLX F2	-0.02595	-0.02656	-0.02747
VUY F3	-0.2980E-08	-0.00261	-0.5960E-08
VLX F3	-0.01320	-0.01385	-0.1192E-07
VUY F4	-0.00072	-0.00216	-0.00225
VLX F4	-0.02595	-0.02656	-0.02747
VUY F5	-0.2980E-08	-0.00261	-0.5960E-08
VLX F5	-0.01320	-0.01385	-0.1192E-07
VUX F1	-0.03234	-0.03197	-0.03152
VLX F1	-0.03234	-0.03197	-0.03152
VUX F2	-0.01943	-0.01916	-0.01884
VLX F2	-0.02538	-0.02746	-0.02978
VUX F3	-0.01104	-0.01112	-0.01123
VLX F3	-0.1490E-08	-0.00184	-0.00395
VUX F4	-0.02538	-0.02746	-0.02978
VLX F4	-0.01943	-0.01916	-0.01884
VUX F5	-0.1490E-08	-0.00184	-0.00395
VLX F5	-0.01104	-0.01112	-0.01123
CIR S6	0.28337	0.28269	0.28194

This is a non-symmetric system. If elements with power are decentered or tilted, the first order properties are probably inadequate in describing the system characteristics.

	POS 1	POS 2	POS 3
INFINITE CONJUGATES			
EFL	3.5538	3.5879	3.6306
BFL	-3.4155	-3.4492	-3.4915
FFL	2.4637	2.4994	2.5437
FNO	1.7918	1.8030	1.8173
AT USED CONJUGATES			
RED	1.0000	0.9996	0.9991
FNO	3.0000	3.0000	3.0000
OBJ DIS	1.0901	1.0901	1.0901
TT	2.4811	2.4811	2.4811
IMG DIS	0.0538	0.0538	0.0538
OAL	1.3372	1.3372	1.3372
PARAXIAL IMAGE			
HT	1.0000	0.9996	0.9991
THI	0.1383	0.1371	0.1360
ANG	10.1432	10.0973	10.0440
ENTRANCE PUPIL			
DIA	1.9834	1.9900	1.9978
THI	4.7769	4.7990	4.8248
EXIT PUPIL			
DIA	3.0471	3.1048	3.1798
THI	-8.8753	-9.0472	-9.2701
STO DIA	0.5667	0.5654	0.5639

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COMPACT AND ATHERMAL VNIR/SWIR SPECTROMETER

FIELD OF THE DISCLOSURE

Embodiments relate to a spectrometer, and more particularly, to a compact athermal imaging spectrometer for VNIR/SWIR spectral range, and, even more particularly, to a compact and athermal Dyson type VNIR/SWIR Spectrometer working in the spectrum of VNIR/SWIR radiation.

BACKGROUND

Imaging spectroscopy in the visible and near infrared (VNIR) 400 nm-1000 nm and short wave infrared (SWIR) 1000 nm-2350 nm spectral ranges allows identifying potential targets as well as studying water and soil properties over large areas. NASA satellites carrying airborne hyperspectral imaging systems are used for identifying a wide variety of surface materials by providing simultaneously many narrow, contiguous spectral bands and higher resolution reflectance spectra for every pixel in a spatial image.

Dyson type spectrometers are described in a paper "OPTICS FOR THE CANADIAN HYPERSPECTRAL MISSION (HERO)". Journal: Sixth International Conference on Space Optics, Proceedings of ESA/CNES ICSO 2006, held 27-30 Jun. 2006 at ESTEC, Noordwijk, The Netherlands. Edited by A. Wilson. ESA SP-621. European Space Agency, 2006. Published on CDROM, p. 8.1. This paper describes a pushbroom Dyson type spectrometer. The spectrometer consists of two spectral channels VNIR and SWIR. The covered band width (spectrum) is 450 nm-2500 nm. The spectrometer incorporates two different gratings spaced from each other by approximately 0.5 meter and two slits. Large volume is needed for spectrometer packaging. Dyson prism blocks make the system heavy. The FPA (focal plane array) is made for 30 μ m pixel size. The spectrometer F# is 2.2.

Spectrometer thermal properties are extremely important for the remote sensing platform configuration and packaging. For temperature sensitive spectrometers, special motor adjusting focal plane array position according to the temperature change is required. That leads to the increase of the packaging envelope and weight of carrying on the airborne platform.

A VNIR/SWIR spectrometer is disclosed in Patent Application US 2014/0071449, Mar. 13, 2014 High Efficiency Multi-channel Spectrometer. The VNIR/SWIR Offner type spectrometer optical system requires substantial envelope and includes multiple mirror, beam splitter, and pair of diffraction gratings.

U.S. Pat. No. 8,520,204, Aug. 27, 2013, discloses a Dyson Type Imaging Spectrometer having Improved Image Quality and Low Distortion. The entry or exit port is located inside the prism (or hemispherical lens)—there is no access for maintenance. No spectral correction over the wide spectrum is performed.

Another spectrometer is disclosed in U.S. Pat. No. 7,609,381, Oct. 27, 2009 Compact High-Throughput Spectrometer apparatus for Hyperspectral Remote Sensing. Only LWIR or VNIR spectral bands may be used, the spectrometer does not feature a combined VNIR/SWIR channel. A single refractive material is used for the VNIR channel, and chromatic aberration is not corrected.

Yet another spectrometer is disclosed in U.S. Pat. No. 7,768,642, Wide Field Compact Imaging Catadioptric Spectrometer, Aug. 3, 2010. This patent describes a wide field

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LWIR spectrometer with a pupil lens for the wide field aberration correction in the LWIR spectral band.

Another spectrometer is disclosed in U.S. Pat. No. 6,980,295 issuing to Lerner on Dec. 27, 2005 and entitled Compact Catadioptric Imaging Spectrometer Utilizing Reflective Grating. Therein disclosed is an imaging spectrometer having an entrance slit, an aspheric lens, grating, and detector. The spectrometer is designed to accommodate LWIR band width 8-13.5 μ m.

Yet another spectrometer is disclosed in U.S. Pat. No. 7,006,217 issuing to Lerner on Feb. 28, 2006 and entitled Compact Catadioptric Imaging Spectrometer Utilizing Immersed Gratings. Therein disclosed is a spectrometer having an entrance slit, a catadioptric lens, a grating that diffracts the light back to the catadioptric lens and a detector. The spectrometer is designed for LWIR band width.

Yet another spectrometer is disclosed in U.S. Pat. No. 8,339,600, Dec. 25, 2012; Dual Waveband Compact Catadioptric Imaging Spectrometer. The spectrometer incorporates ZnSe grating, a curved sapphire prism, and BaF₂ catadioptric lens or dioptric lens with a mirror, the F# is 4.

Even though there has been substantial development in the field of spectrometers for hyperspectral imaging, there is a need for a compact athermal VNIR/SWIR hyperspectral imaging spectrometer. Specifically, there is a need to provide a compact and efficient VNIR/SWIR imaging spectrometer with low F# and wide field of view.

SUMMARY

An embodiment provides a compact and athermal VNIR/SWIR spectrometer comprising a slit; a diffraction grating; an optical system forming spectral components of radiation received by the slit; a plurality of focal plane arrays (FPAs). In embodiments, the spectrometer comprises the slit; a Mangin lens comprising partially reflective and partially refractive surface; a pupil lens; the diffraction grating; an aperture stop; a corrector lens; a beam splitter; a first field lens; a second field lens; a SWIR FPA; and a VNIR FPA; wherein the slit, Mangin lens, pupil lens, diffraction grating, corrector lens, beam splitter, field lenses and FPAs are positioned wherein the slit transmits radiation to a reflective part of the Mangin lens surface and the reflective part directs radiation onto the pupil lens, the pupil lens directs radiation onto the diffraction grating, the diffraction grating diffracts radiation in the SWIR spectrum in a first diffraction order and diffracts radiation in the VNIR spectrum in a second diffraction order and directs radiation onto the pupil lens, the pupil lens directs the SWIR and the VNIR radiation onto the refractive part of the Mangin lens, the Mangin lens directs radiation onto the corrector lens, the corrector lens directs radiation onto the beam splitter, the beam splitter having a coating and transmits the SWIR radiation onto the first field lens and the beam splitter reflects the VNIR radiation onto the second field lens, the first field lens forming an image of the slit at the SWIR FPA and the second field lens forming an image of the slit at the VNIR FPA. In other embodiments, the grating comprises an immersion grating. In subsequent embodiments the grating comprises a reflective grating. For additional embodiments the diffraction grating diffracts SWIR radiation in a first order and VNIR radiation in a second order. In another embodiment, the density of the diffraction grating is 45 grooves/mm. For a following embodiment the aperture stop is located at the grating. In subsequent embodiments the beam splitter transmits SWIR radiation and reflects VNIR radiation. In additional embodiments thermal defocus does not exceed depth of focus in a

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temperature range from -10°C . to 40°C . for both SWIR and VNIR spectrums. In included embodiments the pupil lens is a double path lens. In yet further embodiments the length of the slit is 1.36 inches. In related embodiments the Mangin lens has a positive optical power. For further embodiments the pupil lens has a negative optical power. In ensuing embodiments the diffraction grating has a positive optical power.

Another embodiment provides a compact VNIR/SWIR Spectrometer comprising a slit; a Mangin lens comprising partially reflective and partially refractive surface; a pupil lens; a diffraction grating; an aperture stop; a first corrector lens; a second corrector lens; a single SWIR/VNIR FPA; the slit, Mangin lens, pupil lens, diffraction grating, corrector lenses and FPA are positioned wherein the slit transmits radiation to the reflective part of the Mangin lens surface and the reflective part directs radiation onto the pupil lens, the pupil lens directs radiation onto the diffraction grating, the diffraction grating diffracts radiation in both the SWIR and the VNIR spectrums in a first diffraction order and directs radiation onto the pupil lens, the pupil lens directs radiation onto the refractive part of the Mangin lens, the Mangin lens directs radiation onto the first corrector lens, the first corrector lens directs radiation onto the second corrector lens, the second corrector lens forms image of the slit at the SWIR/VNIR FPA. For yet further embodiments, the grating comprises an immersion grating. For more embodiments, the grating comprises a reflective grating. In continued embodiments, the diffraction grating diffracts both SWIR and VNIR radiation in a first order. For additional embodiments, the aperture stop is located at the grating.

A yet further embodiment provides a compact SWIR spectrometer comprising a slit; a Mangin lens comprising partially reflective and partially refractive surface; a pupil lens; a diffraction grating; an aperture stop; a first corrector lens; a second corrector lens; a single SWIR FPA; the slit, Mangin lens, pupil lens, diffraction grating, corrector lenses and FPA are positioned wherein the slit transmits radiation to the reflective part of the Mangin lens surface and the reflective part directs radiation onto the pupil lens, the pupil lens directs radiation onto the diffraction grating, the diffraction grating diffracts radiation in the SWIR spectrum in a first diffraction order and directs radiation onto the pupil lens, the pupil lens directs radiation onto the refractive part of the Mangin lens, the Mangin lens directs radiation onto the first corrector lens, the first corrector lens directs radiation onto the second corrector lens, the second corrector lens forming an image of the slit at the SWIR FPA.

The features and advantages described herein are not all-inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been selected principally for readability and instructional purposes and not to limit the scope of the inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates ray tracing for a first embodiment of a Compact and Athermal VNIR/SWIR Dyson Spectrometer.

FIG. 2 shows MTF curves for the first embodiment of a Compact and Athermal VNIR/SWIR Dyson Spectrometer configured in accordance with an embodiment.

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FIG. 3 illustrates thermal analysis data for the first embodiment of a Compact and Athermal VNIR/SWIR Dyson Spectrometer configured in accordance with an embodiment.

FIGS. 4A-D represent the prescription of the first embodiment of a Compact and Athermal VNIR/SWIR Dyson Spectrometer configured in accordance with an embodiment.

FIG. 5 illustrates ray tracing for a second embodiment of a Compact and Athermal VNIR/SWIR Dyson Spectrometer.

FIG. 6 shows MTF curves for the second embodiment of a Compact and Athermal VNIR/SWIR Dyson Spectrometer configured in accordance with an embodiment.

FIGS. 7A-D represent the prescription of the second embodiment of a Compact and Athermal VNIR/SWIR Dyson Spectrometer configured in accordance with an embodiment.

FIG. 8 illustrates ray tracing for a third embodiment of a Compact and Athermal VNIR/SWIR Dyson Spectrometer.

FIG. 9 shows MTF curves for the third embodiment of a Compact and Athermal VNIR/SWIR Dyson Spectrometer configured in accordance with an embodiment.

FIGS. 10A-D represent the prescription of the third embodiment of a Compact and Athermal VNIR/SWIR Dyson Spectrometer configured in accordance with an embodiment.

These and other features of the present embodiments will be understood better by reading the following detailed description, taken together with the figures herein described. The accompanying drawings are not intended to be drawn to scale. For purposes of clarity, not every component may be labeled in every drawing.

DETAILED DESCRIPTION

The features and advantages described herein are not all-inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been selected principally for readability and instructional purposes, and not to limit in any way the scope of the inventive subject matter. The invention is susceptible of many embodiments. What follows is illustrative, but not exhaustive, of the scope of the invention.

A compact and athermal Dyson type VNIR/SWIR spectrometer may be used for military and commercial applications. It is very compact and low-weight, and provides excellent spectral resolution in both SWIR and VNIR spectrums. Embodiments can be used for reconnaissance and surveillance purposes. The spectrometer fits existing airborne platforms. Spectrometer embodiments allow implementation of spectral-spatial models for a more accurate segmentation and classification of the images of targets/objects of interest.

In a first embodiment of the invention, a compact and athermal VNIR/SWIR Dyson spectrometer includes a spherical diffraction grating, a pupil lens, a Mangin lens, a corrector lens, a beam splitter, two field lenses and two focal plane arrays (FPA) for VNIR and SWIR spectral channels. Accordingly it is an object of this embodiment to incorporate both VNIR and SWIR hyperspectral components. It is an advantage of this embodiment that it is very compact. It is another advantage of this embodiment that the optical system is corrected for chromatism. It is another advantage of this embodiment that field of view is large. It is another

advantage of this embodiment that F# is low. It is another advantage of this embodiment that spectrometer is athermal.

In a second embodiment, a spectrometer includes a diffraction grating, a pupil lens, a Mangin lens, two corrector lenses and FPA. Both SWIR and VNIR hyperspectral components are incorporated. It is an advantage of a second embodiment that F# is low. It is a feature of this embodiment that one FPA is used for both VNIR and SWIR spectral components. It is a feature of second embodiment that both VNIR and SWIR spectral components are imaged onto one FPA.

In a third embodiment only the SWIR spectral component is used. The spectrometer includes a diffraction grating, a pupil lens, a Mangin lens, two corrector lenses and FPA. It is an advantage of third embodiment that spectrometer is very compact. It is an advantage of this embodiment that F# is low.

It is a feature of embodiments that a field lens is placed adjacent the FPA for image curvature correction. It is another feature of embodiments that the balancing of powers of the lens elements and glass dispersions makes possible the chromatic correction in both SWIR and VNIR spectral regions.

These and other objects, advantages, and features will become readily apparent in view of the following more detailed description.

FIG. 1 illustrates the configuration and ray trace of a first embodiment of the present invention. Dyson type spectrometer **100** includes in direction of ray trace from the slit to the FPA: slit **101**, Mangin lens **102**, pupil lens **103**, diffraction grating **104**, corrector lens **105**, beam splitter **106**, field lens **107**, and FPA **108** for SWIR spectral channel and field lens **109** and FPA **110** for the VNIR spectral channel.

Specifications for the performance are as follows:

Total WL range 2.35-0.4 μm

WL SWIR: 2.35 μm -1 μm

WL VNIR: 0.9 μm -0.5 μm (0.4 μm considered)

Detector 27 μm pixel

FOV $\pm 1^\circ$

Temperature range -10°C . to 40°C .

Number of spatial and spectral channels:

SWIR: 1280 spatial $\times$ 144 spectral, 1.36" spatial $\times$ 0.153" spectral

VNIR: 1280 spatial $\times$ 96 spectral, 1.36" spatial $\times$ 0.102" spectral

Spectral resolution: SWIR 9.4 nm/pixel VNIR 5.2 nm/pixel MTF requirements

SWIR	9.25 cy/mm	0.85	0.85	0.85
SWIR	18.5 cy/mm	0.70	0.70	0.70
VNIR	9.25 cy/mm	0.80	0.80	0.80
VNIR	18.5 cy/mm	0.60	0.60	0.60

Smile, k-stone <0.2 pixel TIR

VNIR/SWIR radiation coming from the object/target is collected by the fore optics onto the spectrometer slit **101**. Slit **101** long side is out of plane of the drawing and is perpendicular to the scan plane. The length of the slit is 1.36 inches. Radiation transmitted by the slit **101** is directed onto the Mangin lens **102** which has a positive optical power. Radiation is refracted by the first surface of the Mangin lens **102**, then is reflected from the reflective part of the second surface of the Mangin lens and then the second time is refracted by the first surface of the Mangin lens and then is directed through the pupil lens **103**, which has a negative optical power, onto the diffraction grating **104**. Aperture stop

AS is located at the grating **104**. Reflective grating **104** has a positive optical power and diffracts the radiation in VNIR/SWIR spectral range into plurality of very narrow spectral bands. Grating **104** is made in a way that VNIR radiation is diffracted in the second diffraction order and SWIR radiation is diffracted in the first diffraction order. Spectral resolution is 5.2 nm in VNIR spectrum and 9.5 nm in SWIR spectrum. Diffracted radiation converged by the diffraction grating **104** goes along a second path through the pupil lens and then goes third time through the first refractive surface of the Mangin lens and refractive part of the Mangin lens' second surface. Still converged radiation is directed by the corrector lens **105**, which has a positive optical power, onto beam splitter **106** which has a special coating providing reflection of VNIR spectral radiation and transmission of SWIR spectral radiation. Transmitted through the beam splitter **106**, SWIR radiation is collected by the field lens **107** onto the SWIR FPA **108**. Field lenses **107** and **109** have positive optical powers. Reflected from the beam splitter, VNIR radiation is focused by the field lens **109** onto VNIR FPA **110**.

Monochromatic and chromatic aberrations depend on the heights and angles of rays at the optical element surface and the refraction index of the material. These aberrations also depend on the shape of the optical element, and on its location with respect to the aperture stop.

For the wide field across the numerical aperture aberrational correction, a special balance of the optical powers of the components and a certain relative orientation the components with respect to each other is required. The Mangin lens **102** is shaped as a double convex lens, the pupil lens **103** is shaped as a negative meniscus lens whose convex surface faces toward the diffraction grating **104**, the diffraction grating **104** is shaped as a concave reflective surface facing the incoming beam, the corrector lens **105** is shaped as a double convex lens and the field lenses **107** and **109** are shaped as double convex lenses. The Mangin lens **102** aberrational contribution to wide beam low order spherical aberration is compensated by the corrector lens **105**, the cross field aberration are corrected by the pupil lens **103**; that allows the increase of the slit **101** length and leads to the more efficient system. The field lenses **107** and **109** correct for the field curvature along the slit.

For the residual high order spherical aberration and coma correction, first surface of the Mangin lens, second surface of the pupil lens, diffraction grating surface and second surface of the corrector lens are made aspherical, according to the ray tracing from the slit to the FPA.

In order for chromatic correction in VNIR-SWIR spectrum, a special combination of all components materials is required. The contribution of the optical element to the total axial color is proportional to the square of axial marginal ray height at the lens, its optical power, and the reciprocal of the Abbe number of the lens material. The Abbe number is a measure of the material's light dispersion in relation to the refractive index. The Abbe number V_d is given by:

$$V_d = (n_d - 1) / (n_F - n_C)$$

where n_d is the index of refraction of the glass at the wavelength of the helium line d (587.6 nm), n_F is the index of refraction at the blue cadmium line F' (479.99 nm), and n_C is the index of refraction at the red cadmium line C' (643.85 nm). Accordingly, the smaller the value of V_d , the greater the chromatic dispersion of the glass.

In order for chromatic correction in VNIR-SWIR spectrum, a special combination of all components' material properties is required. Mangin lens **102** is made out of CaF₂,

pupil lens **103** is made of NKZFS8 Schott glass, Corrector lens **105** is made of CaF2 and field lenses **107** and **109** are made of NSK11 Schott glass.

The mutual combination of optical elements' materials refractive indices and Abbe numbers provides monochromatic and achromatic correction of the spectrometer **100**.

When ambient temperature changes, the shapes and positions of optical elements will change, and the focal length and position of an image formed by the lens will change as well. This is caused by glass expansion and changes in the glass refractive index with temperature. This dependence on temperature can have a significant impact on lens performance. So as to compensate for these changes, either the focal plane array has to be adjusted along the optical axis, or some elements inside the lens have to be moved. However, this approach is highly undesirable, because additional electronics and software are needed to perform and monitor the necessary adjustments.

On the other hand, a lens does not need thermal adjustment when the change of the focus position within the required temperature range stays inside the depth of focus of the lens. The diffraction depth of focus (DOF) is defined by:

$$DOF = \lambda / NA^2$$

where λ is the wavelength and NA is numerical aperture at the image space

For $\lambda=1000$ nm and F#3.3 (NA=0.1515): $DOF \approx 0.0435$ mm.

Therefore, in this example, if the lens design meets a requirement that all changes of the focus position over a specified range of temperature changes are inside 0.0435 mm, no refocusing is required.

Temperature change also causes the expansion of the optical elements. The Opto-thermal expansion coefficient β of an optical element is a property of the glass material, and it does not depend on the focal length or shape factor of the individual optics. For a single optical element:

$$\beta = \alpha (dn/dT) / (n-1)$$

Where:

α =the thermal expansion coefficient of the glass

n =the refractive index of the glass at the current wavelength

T =ambient temperature

Contribution of thermal expansion of the optical elements glass compare to the refractive index change with temperature is rather small and usually does not have a noticeable effect DOF change.

The mutual combination of changes of refractive index with temperature of the optical elements provides athermalization of the spectrometer **100**.

In the embodiment of FIG. 1, the optical elements satisfy the following relations:

$$1 < F'/F'_{ML} < 1.45$$

$$1.3 < F'/F'_C < 1.75$$

$$-0.55 < F'/F'_{PL} < -0.35$$

$$2.5 < F'/F'_{DG} < 3.8$$

$$0.35 < F'/F'_{FL} < 0.75$$

$$2.5 < F'/OAL < 3.5$$

$$7.5 < F'/DEC < 8.5$$

$$2.5 < V_{ML}/V_{PL} < 3$$

$$0.8 < V_{ML}/V_C < 1.2$$

$$1.3 < V_{ML}/V_{FL} < 1.75$$

$$-4.8 < dn/dT_{ML}/dn/dT_{PL} < -3.4$$

$$0.8 < dn/dT_{ML}/dn/dT_C < 1.2$$

$$-4.8 < dn/dT_{ML}/dn/dT_{FL} < -3.3$$

Wherein:

F' is the focal length of the spectrometer **100**

F'_{ML} is the focal length of the Mangin lens **102**

F'_C is the focal length of the corrector lens **105**

F'_{PL} is the focal length of the pupil lens **103**

F'_{DG} is the focal length of the diffraction grating **104**

F'_{FL} is the focal length of the field lenses **107** and **109**

OAL is the overall length of the spectrometer **100** along the optical axis from the slit **101** to the FPA **108**

DEC is the decentration of the slit **101** with respect to the optical axis in the direction perpendicular to the length of the slit

V_{ML} is the Abbe number for the current wave length of the glass of the Mangin lens **102**

V_{PL} is the Abbe number for the current wave length of the glass of the pupil lens **103**

V_C is the Abbe number for the current wave length of the corrector lens **105**

V_{FL} is the Abbe number for the current wave length of the glass of the field lenses **107** and **109**

dn/dT_{ML} is the refractive index change with temperature for the Mangin lens **102**

dn/dT_{PL} is the refractive index change with temperature for the pupil lens **103**

dn/dT_C is the refractive index change with temperature for the corrector lens **105**

dn/dT_{FL} is the refractive index change with temperature for the field lenses **107** and **109**

The selection of the optical powers of the optical elements, the selection of the refractive indices and the Abbe numbers as well as dn/dT values of the used glasses, provides a compact wide field, low NA and athermal spectrometer. The defocusing caused by changes in temperature is less than the depth of focus of the lens.

FIG. 2 presents MTF data for the embodiment of FIG. 1. The field is flat and polychromatic MTF shows good contrast over the entire field for F#3.3.

FIG. 3 presents defocus of the first embodiment with respect to the temperature change. For both VNIR and SWIR channels, defocus is within the depth of focus for a specified range of -10° C. to $+40^\circ$ C.

Spectral and smile distortion are less than 0.2 pixel.

FIG. 4A-D present the prescription of the first embodiment for both VNIR and SWIR channels.

FIG. 5 is an illustration **500** of the second embodiment of the VNIR/SWIR spectrometer. Spectrometer **200** consists of (by the ray trace from the slit to the FPA): slit **201**, Mangin lens **202**, pupil lens **203**, diffraction grating **204**, first corrector lens **205**, second corrector lens **206** and FPA **207**. Only one diffraction order is used for both VNIR and SWIR channels and hyperspectral images of the slit are analyzed only at one FPA plane.

VNIR/SWIR radiation coming from the object/target is collected by the fore optics onto the spectrometer slit **201**. Slit **201** long side is out of plane of the drawing and is perpendicular to a scan plane. Length of the slit is 1.36 inches. Radiation transmitted by the slit **201** is directed onto the Mangin lens **202** which has a positive optical power.

Radiation is refracted by the first surface of the Mangin lens **202**, then is reflected from the reflective part of the second surface of the Mangin lens and then a second time is refracted by the first surface of the Mangin lens and then is directed through the pupil lens **203**, which has a negative optical power, onto the spherical diffraction grating **204**. Aperture stop AS is located at the grating **204**. Reflective grating **204** has a positive optical power and diffracts the radiation in the VNIR/SWIR spectral range into a plurality of very narrow spectral bands, at that, only first order of diffraction is used. Diffracted radiation converged by the diffraction grating **204** goes by a second path through the pupil lens and then goes a third time through the first refractive surface of the Mangin lens **202** and refractive part of the Mangin lens' second surface. Still converged radiation is directed by the first corrector lens **205**, which has a positive optical power, onto the second corrector lens **206** which has a positive optical power. Second corrector lens **206** focuses all spectral components of the slit **201** onto FPA **207**. The spectral range for the VNIR channel is 400 nm-900 nm and the spectral range for the SWIR channel is 1000 nm-2400 nm.

The Mangin lens **202** is shaped as a double convex lens and the first surface of the Mangin lens is formed aspherical, the pupil lens **203** is shaped as a negative meniscus lens whose convex surface faces toward the diffraction grating **204**, the diffraction grating **204** is shaped as a concave reflective surface facing the incoming beam, the first corrector lens **205** is shaped as a double convex lens and the second corrector lens **206** is shaped as a positive meniscus lens, whose convex surface faces the FPA. First surface of the Mangin lens **202**, second surface of the pupil lens **203**, first surface of the first corrector lens **205** and second surface of the second corrector lens **206** are formed as aspherical. Corrector lenses **205** and **206** compensate for the spherical aberration, coma, and astigmatism introduced by the Mangin lens **202** and grating **203**. Residual high order spherical aberration and coma are corrected by the aspherical surfaces of the Mangin lens **202** and pupil lens **203**, and residual high order astigmatism and field curvature are corrected by the first aspherical surface of the corrector lens **205** and second aspherical surface of the corrector lens **206**. For chromatic aberration correction, the Mangin lens **202** is made of CaF₂, pupil lens **203** is made of glass NKZFS8 Schott, first corrector lens **205** is made of NKZFS8 Schott and second corrector lens **206** is made of NSK11 Schott glass.

The mutual combination of optical components optical powers, glasses' refractive indices and Abbe numbers of the optical elements provide monochromatic and chromatic correction of the spectrometer **200**.

In the embodiment of FIG. **5**, the optical elements parameters satisfy the following relations:

$$0.95 < F'_{200} / F'_{ML202} < 1.55$$

$$-0.45 < F'_{200} / F'_{PL203} < -0.2$$

$$1.5 < F'_{200} / F'_{C205} < 1.85$$

$$0.35 < F'_{200} / F'_{C206} < 0.6$$

$$2.15 < F'_{200} / F'_{DG204} < 2.65$$

$$2.25 < F' / OAL_{200} < 2.8$$

$$7.75 < F'_{200} / DEC_{200} < 8.6$$

$$2.6 < V_{ML202} / V_{PL203} < 3.5$$

$$2.6 < V_{ML202} / V_{C205} < 3.5$$

$$1.2 < V_{ML202} / V_{C206} < 2$$

Wherein:

F'_{200} is the focal length of the spectrometer **200**

F'_{ML202} is the focal length of the Mangin lens **202**

F'_{C205} is the focal length of the first corrector lens **205**

F'_{C206} is the focal length of the second corrector lens **206**

F'_{PL203} is the focal length of the pupil lens **203**

F'_{DG204} is the focal length of the diffraction grating **204**

OAL_{200} is the overall length of the spectrometer **200** along the optical axis from the slit **201** to the FPA **207**

DEC_{200} is the decentration of the slit **201** with respect to the optical axis in the direction perpendicular to the length of the slit

V_{ML202} is the Abbe number for the current wave length of the glass of the Mangin lens **202**

V_{PL203} is the Abbe number for the current wave length of the glass of the pupil lens **203**

V_{C205} is the Abbe number for the current wave length of the first corrector lens **205**

V_{C206} is the Abbe number for the current wave length of the second corrector lens **206**

The selection of the optical powers of the optical elements, the selection of the refractive indices and the Abbe numbers of the used glasses provides a wide field, low NA spectrometer utilizing only one FPA for spectral components of both VNIR and SWIR channels.

FIG. **6** presents MTF data **600** for the embodiment of FIG. **5**. Polychromatic MTF shows good contrast over the entire field for F#3.3.

Spectral and smile distortion are less than 0.2 pixel.

FIG. **7A-D** present the prescription of the second embodiment.

FIG. **8** is an illustration of a third embodiment **800** of the present invention. Spectrometer **800** consists of, in the order of the ray trace from the slit to the FPA: slit **801**, Mangin lens **802**, pupil lens **803**, diffraction grating **804**, first corrector lens **805**, second corrector lens **806** and FPA **807**. Only SWIR radiation is accepted by spectrometer **800** and only SWIR hyperspectral images of the slit **801** are analyzed only at the FPA **807**.

SWIR radiation coming from the object/target is collected by the fore optics onto the spectrometer slit **801**. Slit **801** long side is out of plane of the drawing and is perpendicular to a scan plane. Length of the slit is 0.96 inches. Radiation transmitted by the slit **801** is directed onto the Mangin lens **802** which has a positive optical power. Radiation is refracted by the first surface of the Mangin lens **802**, then is reflected from the reflective part of the second surface of the Mangin lens and then second time is refracted by the first surface of the Mangin lens and then is directed through the pupil lens **803**, which has a negative optical power, onto the spherical diffraction grating **804**. Aperture stop AS is located at the grating **804**. Reflective grating **804** has a positive optical power and diffracts the radiation in the SWIR spectral range into a plurality of very narrow spectral bands, at that, only first order of diffraction is used. Diffracted radiation converged by the diffraction grating **804** goes by a second path through the pupil lens **803** and then goes a third time through the first refractive surface of the Mangin lens **802** and refractive part of the Mangin lens' second surface. Still converged radiation is directed by the first corrector lens **805**, which has a positive optical power, onto the second corrector lens **806** which has a positive optical power. Second corrector lens **806** focuses all spectral components of the slit **801** onto FPA **807**. Spectral range for the SWIR

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channel is 1000 nm-1700 nm. The Mangin lens **802** is shaped as a double convex lens, the pupil lens **803** is shaped as a negative meniscus lens whose convex surface faces toward the Mangin lens **802**, the diffraction grating **804** is shaped as a concave reflective surface facing the incoming beam, the first corrector lens **805** is shaped as a double convex lens and the second corrector lens **806** is shaped as a positive meniscus lens, whose convex surface faces FPA. First surface of the Mangin lens **802**, second surface of the pupil lens **803**, first surface of the first corrector lens **805** and second surface of the second corrector lens **806** are formed as aspherical. The diffraction grating **803** is tilted contra clock direction with respect to the optical axis of the Mangin lens by about 1 degree, around the axis perpendicular to the optical axis (tilt is in the plane of the drawing of FIG. 8), in order to compensate for smile distortion and astigmatism. Corrector lenses **805** and **806** compensate for the wide beam aberrations of spherical and coma introduced by the Mangin lens **802** and grating **803**. Residual high order aberration is corrected by the aspherical surfaces of the Mangin lens **802** and pupil lens **804**, and residual high order astigmatism and field curvature are corrected by the first aspherical surface of the corrector lens **805** and second aspherical surface of the corrector lens **806**. For chromatic aberration correction, the Mangin lens **802** is made of CaF₂, pupil lens **803** is made of glass NKZFS8 Schott, first corrector lens **805** is made of SFPL53 Ohara and second corrector lens **806** is made of STIH53 Ohara glasses.

The configuration of the spectrometer components, mutual combination of optical powers, glasses refractive indices and Abbe numbers provide the monochromatic and polychromatic aberrational correction of the spectrometer **800**.

In the embodiment of FIG. 8, the optical elements parameters satisfy the following relations:

$$0.55 < F'_{800}/F'_{ML802} < 0.85$$

$$-0.1 < F'_{800}/F'_{PL803} < -0.055$$

$$0.9 < F'_{800}/F'_{C805} < 1.4$$

$$0.3 < F'_{800}/F'_{C806} < 0.6$$

$$1.5 < F'_{800}/F'_{DG804} < 2.5$$

$$1.2 < F'_{800}/OAL_{800} < 1.6$$

$$2.5 < F'_{800}/DEC_{800} < 4.5$$

$$0.25^\circ \beta_{804} < 4^\circ$$

$$2.4 < V_{ML802}/V_{PL803} < 3.5$$

$$0.8 < V_{ML802}/V_{C805} < 1.2$$

$$3.5 < V_{ML802}/V_{C806} < 4.5$$

Wherein:

F'_{800} is the focal length of the spectrometer **800**

F'_{ML802} is the focal length of the Mangin lens **802**

F'_{C805} is the focal length of the first corrector lens **805**

F'_{C806} is the focal length of the second corrector lens **806**

F'_{PL803} is the focal length of the pupil lens **803**

F'_{DG804} is the focal length of the diffraction grating **804**

OAL_{800} is the overall length of the spectrometer along the optical axis from the slit **801** to the FPA **807**

DEC_{800} is the decentration of the slit **801** with respect to the optical axis in the direction perpendicular to the length of the slit

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β_{804} is diffraction grating **804** counter-clockwise rotation angle, around the axis perpendicular to the optical axis of Mangin lens **802**

V_{ML802} is the Abbe number for the current wave length of the glass of the Mangin lens **802**

V_{PL803} is the Abbe number for the current wave length of the glass of the pupil lens **803**

V_{C805} is the Abbe number for the current wave length of the glass of the first corrector lens **805**

V_{C806} is the Abbe number for the current wave length of the glass of the second corrector lens **806**

The selection of the optical powers of the optical elements, the selection of the refractive indices and the Abbe numbers of the used glasses, provides a very compact, low NA spectrometer with F#3, working in SWIR spectrum.

MTF data for the embodiment of FIG. 8 is presented in FIG. 9. Polychromatic MTF shows good contrast over the entire field for F#3.3.

Spectral and smile distortion are less than 0.2 pixel.

FIGS. 10A-D present the prescription of the third embodiment.

Example elements for the first embodiment follow. A compact and Athermal VNIR/SWIR Spectrometer as in the first embodiment wherein: said corrector lens has a positive optical power. A compact and Athermal VNIR/SWIR Spectrometer as in the first embodiment wherein: said first field lens positioned at SWIR FPA has a positive optical power. A compact and athermal VNIR/SWIR Spectrometer as in the first embodiment wherein: said second field lens positioned at SWIR FPA has a positive optical power. A compact and athermal VNIR/SWIR Spectrometer as in the first embodiment wherein: said Mangin lens is shaped as a double convex lens. A compact and athermal VNIR/SWIR Spectrometer as in the first embodiment wherein: said pupil lens is shaped as a negative meniscus lens whose convex surface faces toward said diffraction grating. A compact and athermal VNIR/SWIR Spectrometer as in the first embodiment wherein: said diffraction grating is shaped as a concave reflective surface facing the incoming beam. A compact and athermal VNIR/SWIR Spectrometer as in the first embodiment wherein: said corrector lens is shaped as a double convex lens. A compact and athermal VNIR/SWIR Spectrometer as in the first embodiment wherein: said first field lens positioned at SWIR FPA is shaped as a double convex lens. A compact and athermal VNIR/SWIR Spectrometer as in the first embodiment wherein: said second field lens positioned at VNIR FPA is shaped as a double convex lens. A compact and athermal VNIR/SWIR Spectrometer as in the first embodiment wherein: first surface of said Mangin lens is formed aspherical. A compact and athermal VNIR/SWIR Spectrometer as in the first embodiment wherein: second surface of said pupil lens is formed aspherical. A compact and athermal VNIR/SWIR Spectrometer as in the first embodiment wherein: first surface of said corrector lens is formed aspherical.

Example elements for the second embodiment follow. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: said pupil lens is a double path lens. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: length of said slit is 1.36 inches. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: said Mangin lens has a positive optical power. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: said pupil lens has a negative optical power. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: said diffraction grating has a positive optical power. A Compact VNIR/SWIR Spec-

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trometer as in the second embodiment wherein: said first corrector lens has a positive optical power. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: said second corrector lens has a positive optical power. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: said Mangin lens is shaped as a double convex lens. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: said pupil lens is shaped as a negative meniscus lens whose convex surface faces toward said diffraction grating. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: said diffraction grating is shaped as a concave reflective surface facing the incoming beam. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: said first corrector lens is shaped as a double convex lens. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: said second corrector lens is shaped as a double convex lens whose convex surface faces toward said FPA. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: first surface of said Mangin lens is formed aspherical. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: second surface of said pupil lens is formed aspherical. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: first surface of said first corrector lens is formed aspherical. A Compact VNIR/SWIR Spectrometer as in the second embodiment wherein: second surface of said second corrector lens is formed aspherical.

Example elements for the third embodiment follow. A Compact SWIR Spectrometer as in the third embodiment wherein said grating comprises an immersion grating. A Compact SWIR Spectrometer as in the third embodiment wherein: said grating comprises a reflective grating. A Compact SWIR Spectrometer as in the third embodiment wherein: said diffraction grating diffracts SWIR radiation in a first order. A Compact SWIR Spectrometer as in the third embodiment wherein: said aperture stop is located at the grating. A Compact SWIR Spectrometer as in the third embodiment wherein: said pupil lens is a double path lens. A Compact and Athermal VNIR/SWIR Spectrometer as in the third embodiment wherein: length of said slit is 0.96 inches. A Compact SWIR Spectrometer as in the third embodiment wherein: said Mangin lens has a positive optical power. A Compact SWIR Spectrometer as in the third embodiment wherein: said pupil lens has a negative optical power. A Compact SWIR Spectrometer as in the third embodiment wherein: said diffraction grating has a positive optical power. A Compact SWIR Spectrometer as in the third embodiment wherein: said first corrector lens has a positive optical power. A Compact SWIR Spectrometer as in the third embodiment wherein: said second corrector lens has a positive optical power. A Compact SWIR Spectrometer as in the third embodiment wherein: said Mangin lens is shaped as a double convex lens. A Compact SWIR Spectrometer as in the third embodiment wherein: said pupil lens is shaped as a negative meniscus lens whose concave surface faces toward said diffraction grating. A Compact SWIR Spectrometer as in the third embodiment wherein: said diffraction grating is shaped as a concave reflective surface facing the incoming beam. A Compact SWIR Spectrometer as in the third embodiment wherein: said first corrector lens is shaped as a double convex lens. A Compact SWIR Spectrometer as in the third embodiment wherein: said second corrector lens is shaped as a double convex lens whose convex surface faces toward said FPA. A Compact SWIR Spectrometer as in the third embodiment wherein: first surface of said Mangin lens is formed aspherical. A Compact SWIR Spectrometer as

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in the third embodiment wherein: second surface of said pupil lens is formed aspherical. A Compact SWIR Spectrometer as in the third embodiment wherein: first surface of said first corrector lens is formed aspherical.

The foregoing description of the embodiments has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of this disclosure. It is intended that the scope of the present disclosure be limited not by this detailed description, but rather by the claims appended hereto.

A number of implementations have been described. Nevertheless, it will be understood that various modifications may be made without departing from the scope of the disclosure. Although operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results.

Each and every page of this submission, and all contents thereon, however characterized, identified, or numbered, is considered a substantive part of this application for all purposes, irrespective of form or placement within the application. This specification is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of this disclosure. Other and various embodiments will be readily apparent to those skilled in the art, from this description, figures, and the claims that follow. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto.

What is claimed is:

1. An athermal VNIR/SWIR Dyson type spectrometer comprising:

- a slit;
- a diffraction grating;
- an optical system forming spectral components of radiation received by said slit;
- a plurality of focal plane arrays (FPAs);
- wherein $2.5 < F'/OAL < 3.5$;
- where

- F' is the focal length of the spectrometer; and
- OAL is the overall length of the spectrometer along the optical axis from the slit to the FPAs;
- wherein said overall length of said Dyson type spectrometer is from 2.5 inches to 4 inches;
- a wavelength range of said VNIR/SWIR is 400 nm to 2350 nm;
- a slit length of 0.48 inch to 0.68 inch; and
- an $F\#$ is 3 to 3.3.

2. The spectrometer of claim 1 comprising:

- said slit;
- a Mangin lens comprising a partially reflective and partially refractive surface;
- a pupil lens;
- said diffraction grating;
- an aperture stop;
- a corrector lens;
- a beam splitter;
- a first field lens;
- a second field lens;
- a SWIR FPA; and
- a VNIR FPA;

wherein said slit, Mangin lens, pupil lens, diffraction grating, corrector lens, beam splitter, field lenses and FPAs are positioned wherein said slit transmits radia-

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tion to a reflective part of said Mangin lens surface and said reflective part directs radiation onto said pupil lens, said pupil lens directs radiation onto said diffraction grating, said diffraction grating diffracts radiation in said SWIR spectrum in a first diffraction order and diffracts radiation in said VNIR spectrum in a second diffraction order and directs radiation onto said pupil lens, said pupil lens directs said SWIR and said VNIR radiation onto said refractive part of said Mangin lens, said Mangin lens directs radiation onto said corrector lens, said corrector lens directs radiation onto said beam splitter, said beam splitter having a coating and transmits said SWIR radiation onto said first field lens and said beam splitter reflects said VNIR radiation onto said second field lens, said first field lens forming an image of said slit at said SWIR FPA and said second field lens forming an image of said slit at said VNIR FPA.

3. The spectrometer of claim 2, wherein said beam splitter transmits SWIR radiation and reflects VNIR radiation.

4. The spectrometer of claim 2, wherein thermal defocus does not exceed depth of focus in a temperature range from -10°C to 40°C for both SWIR and VNIR spectrums.

5. The spectrometer of claim 2, wherein said pupil lens is a double path lens.

6. The spectrometer of claim 2, wherein a length of said slit is 1.36 inches.

7. The spectrometer of claim 2, wherein said Mangin lens has a positive optical power.

8. The spectrometer of claim 2, wherein said pupil lens has a negative optical power.

9. The spectrometer of claim 2, wherein said diffraction grating has a positive optical power.

10. The spectrometer of claim 1, wherein said grating comprises an immersion grating.

11. The spectrometer of claim 1, wherein said grating comprises a reflective grating.

12. The spectrometer of claim 1, wherein said diffraction grating diffracts SWIR radiation in a first order and VNIR radiation in a second order.

13. The spectrometer of claim 1, wherein a density of said diffraction grating is 45 grooves/mm.

14. The spectrometer of claim 1, wherein an aperture stop is located at said grating.

15. A VNIR/SWIR Dyson type spectrometer comprising:

a slit;

a Mangin lens comprising a partially reflective and partially refractive surface;

a pupil lens;

a diffraction grating;

an aperture stop;

a first corrector lens;

a second corrector lens;

a single SWIR/VNIR FPA;

wherein said overall length of said Dyson type spectrometer is from 2.5 inches to 4 inches;

a wavelength range of said VNIR/SWIR is 400 nm to 2350 nm;

a slit length of 0.48 inch to 0.68 inch; and an $F\#$ is 3 to 3.3;

said slit, Mangin lens, pupil lens, diffraction grating, corrector lenses and FPA are positioned wherein said slit transmits radiation to said reflective part of said Mangin lens surface and said reflective part directs radiation onto said pupil lens, said pupil lens directs radiation onto said diffraction grating, said diffraction grating diffracts radiation in at least one of said SWIR

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and said VNIR spectrums in a first diffraction order and directs radiation onto said pupil lens, said pupil lens directs radiation onto said refractive part of said Mangin lens, said Mangin lens directs radiation onto said first corrector lens, said first corrector lens directs radiation onto said second corrector lens, said second corrector lens forms image of said slit at said SWIR/VNIR FPA;

wherein focal lengths of lens and optical groups satisfy the relationships

$$0.95 < F'_{200}/F'_{ML202} < 1.55$$

$$-0.45 < F'_{200}/F'_{PL203} < -0.2$$

$$1.5 < F'_{200}/F'_{C205} < 1.85$$

$$0.35 < F'_{200}/F'_{C206} < 0.6$$

$$2.15 < F'_{200}/F'_{DG204} < 2.65$$

$$2.25 < F'/OAL_{200} < 2.8$$

$$7.75 < F'_{200}/DEC_{200} < 8.6$$

$$2.6 < V_{ML202}/V_{PL203} < 3.5$$

$$2.6 < V_{ML202}/V_{C205} < 3.5$$

$$1.2 < V_{ML202}/V_{C206} < 2$$

where

F'_{200} is the focal length of the spectrometer;

F'_{ML202} is the focal length of the Mangin lens;

F'_{C205} is the focal length of the first corrector lens;

F'_{C206} is the focal length of the second corrector lens;

F'_{PL203} is the focal length of the pupil lens;

F'_{DG204} is the focal length of the diffraction grating;

OAL_{200} is the overall length of the spectrometer along the optical axis from the slit to the FPA;

DEC_{200} is the decentration of the slit with respect to the optical axis in the direction perpendicular to the length of the slit;

V_{ML202} is the Abbe number for the current wave length of the glass of the Mangin lens;

V_{PL203} is the Abbe number for the current wave length of the glass of the pupil lens;

V_{C205} is the Abbe number for the current wave length of the first corrector lens; and

V_{C206} is the Abbe number for the current wave length of the second corrector lens.

16. The spectrometer of claim 15, wherein said grating comprises an immersion grating.

17. The spectrometer of claim 15, wherein said grating comprises a reflective grating.

18. The spectrometer of claim 15, wherein said diffraction grating diffracts both SWIR and VNIR radiation in a first order.

19. The spectrometer of claim 15, wherein said aperture stop is located at the grating.

20. A SWIR Dyson type spectrometer comprising:

a slit;

a Mangin lens comprising a partially reflective and partially refractive surface;

a pupil lens;

a diffraction grating;

an aperture stop;

a first corrector lens;

a second corrector lens;

a single SWIR FPA;

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wherein an overall length of said Dyson type spectrometer is from 2.5 inches to 4 inches;

a wavelength range of said VNIR/SWIR is 400 nm to 2350 nm;

a slit length of 0.48 inch to 0.68 inch; and 5

an F# is 3 to 3.3;

said slit, Mangin lens, pupil lens, diffraction grating, corrector lenses and FPA are positioned wherein said slit transmits radiation to said reflective part of said Mangin lens surface and said reflective part directs radiation onto said pupil lens, said pupil lens directs radiation onto said diffraction grating, said diffraction grating diffracts radiation in said SWIR spectrum in a first diffraction order and directs radiation onto said pupil lens, said pupil lens directs radiation onto said refractive part of said Mangin lens, said Mangin lens directs radiation onto said first corrector lens, said first corrector lens directs radiation onto said second corrector lens, said second corrector lens forming an image of said slit at said SWIR FPA; 10 15 20

wherein focal lengths of lens and optical groups satisfy the relationships

$$0.55 < F'_{800}/F'_{ML802} < 0.85$$

$$-0.1 < F'_{800}/F'_{PL803} < -0.055$$

$$0.9 < F'_{800}/F'_{C805} < 1.4$$

$$0.3 < F'_{800}/F'_{C806} < 0.6$$

$$1.5 < F'_{800}/F'_{DG804} < 2.5$$

$$1.2 < F'_{800}/OAL_{800} < 1.6$$

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$$2.5 < F'_{800}/DEC_{800} < 4.5;$$

$$0.25^\circ < \beta_{804} < 4^\circ$$

$$2.4 < V_{ML802}/V_{PL803} < 3.5$$

$$0.8 < V_{ML802}/V_{C805} < 1.2$$

$$3.5 < V_{ML802}/V_{C806} < 4.5$$

wherein:

F'_{800} is the focal length of the spectrometer;

F'_{ML802} is the focal length of the Mangin lens;

F'_{C805} is the focal length of the first corrector lens;

F'_{C806} is the focal length of the second corrector lens;

F'_{PL803} is the focal length of the pupil lens;

F'_{DG804} is the focal length of the diffraction grating;

OAL_{800} is the overall length of the spectrometer along the optical axis from the slit to the FPA;

DEC_{800} is the decentration of the slit with respect to the optical axis in the direction perpendicular to the length of the slit;

β_{804} is diffraction grating counter-clockwise rotation angle, around the axis perpendicular to the optical axis of Mangin lens

V_{ML802} is the Abbe number for the current wave length of the glass of the Mangin lens;

V_{PL803} is the Abbe number for the current wave length of the glass of the pupil lens;

V_{C805} is the Abbe number for the current wave length of the glass of the first corrector lens; and

V_{C806} is the Abbe number for the current wave length of the glass of the second corrector lens. 25 30

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